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project record

Criteria and Standards for Drift Sampling Forest Pesticide Spray

ED & T 2353
SPRAY DEPOSIT ASSESSMENT

OCTOBER 1977

USDA ■ Forest Service Equipment Development Center ■ Missoula, Montana

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CRITERIA AND STANDARDS FOR DRIFT SAMPLING
FOREST PESTICIDE SPRAY

ED&T 2353

Spray Deposit Assessment

By

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October 1977

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Missoula, Montana 59801

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ABSTRACT

The Equipment Development Center at Missoula (MEDC) has been asked to evaluate sampling devices and develop a standard sampler (or samplers) to detect and measure significant amounts of pesticides that drift outside the target during aerial applications over forest terrain.

This preliminary report summarizes the principles of drift sampling and recommends criteria for selecting samplers and standards for reporting drift that will be sent to those concerned with drift information. Comments on these recommended criteria are solicited to allow us to establish uniform standards for sampling and reporting drift and to allow us to develop a standard sampler (or samplers).

A report on Equipment Development and Test Project 2353, Spray Deposit Assessment Systems, funded by the Forest Insect and Disease Management Staff.

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INTRODUCTION

The Equipment Development Center (MEDC) at Missoula, Montana, has been asked to provide a standard sampler (or samplers) to detect and measure significant amounts of pesticides that have drifted outside a target area during aerial applications over complex forest terrain.

This is a preliminary report on that work. It summarizes the principles of drift sampling and recommends criteria and standards for sampling drift. This report will be sent to a diverse group concerned with collecting, analyzing, or using drift information to solicit their comments on the recommended criteria. These comments will allow us to establish uniform standards for sampling and reporting drift, which is a necessary first step before we can evaluate existing sampling devices and develop and implement a standard sampler (or samplers) for Forest Service use.

BACKGROUND

Applying sprays aerially inevitably produces very small droplets that drift outside the target, and under adverse conditions even droplets that would normally settle within the target will move outside the target area. Detecting pesticides outside the target area helps evaluate environmental damage as well as compare spray systems and compare mixes, validate drift models, and develop environmental policies.

Accounting for the fate of all the spray material would be an enormous task. Figure 1 is an adaptation of a diagrammatic model (Southwell 1974) used to subjectively describe the fate of pesticide spray. MEDC is concerned with the coarse aerosol carried off target by the surface wind before spray is deposited downwind on soil, plants, water, or animals (heavy outline in figure 1).

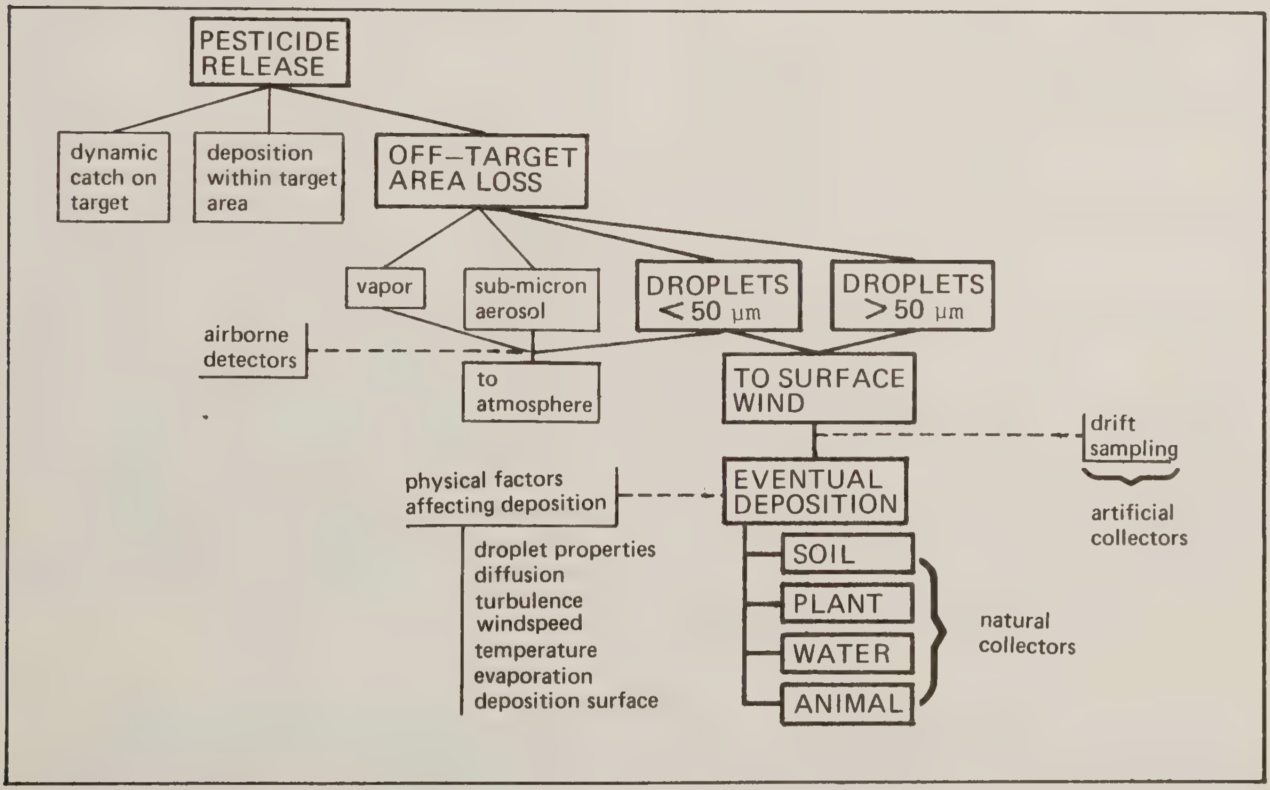

Figure 1.--Diagram of pesticide travel and scope of drift sampling (heavy outline).

Measuring drift into nontarget forest spray areas has been accomplished in two ways on pilot and operational projects: Droplets falling on ground deposition cards have been collected and some air sampling has been done on an experimental basis in a forest by Barry (1974) and Bergen (1976).

Nonforest tests have been conducted with spray aircraft flying over deposit card lines placed on the ground under favorable meteorological conditions. Spray release was extended considerably beyond the card line to insure capturing small droplets with shallow trajectories. Mass recovery varied between 15 and 55 percent (Dumbauld and Rafferty 1976 ; Orchard and others 1974). Even allowing for errors in methods, these tests show that a substantial portion of the spray cloud may evaporate or continue to drift beyond the target area. The airborne droplets are of course subject to impaction and impingement on foliage before leaving the target area. Therefore obstacles such as branches and leaves in the drift zone would scavenge a portion of the droplets.

A variety of aerosol and particulate sampling devices developed for air pollution studies, public health, spore transport, and chemical and biological warfare have been adapted for sampling drift of forest and agricultural chemicals. No uniform method of reporting results and no primary reference standards for sampling spray drift have been established for either forest or agricultural spraying. Even in public health and air pollution studies where standards for sampling and reporting results have been established, there is no unbiased standard sampler to collect and measure the particulate or droplets.

MEDC will limit its search for a standard sampler to artificial collectors in surface winds, which measure the amount of material available for deposition at a point or beyond that point.

There is of course merit and need for measuring deposits on natural collectors and testing should be pursued by those scientists concerned with water, soil, or a particular organism.

Even after a successful standard sampler (or samplers) has been developed, efforts should continue to establish relationships between deposits on artificial collectors and deposits on natural collectors to allow us to evaluate effects of drift.

Every sampler has limitations. Objectives of the investigator are of primary importance in selecting the most suitable sampler. Defining sampling objectives should narrow the scope of development and evaluation to manageable proportions.

Potential uses of drift samplers in conjunction with spraying forest pesticides include:

1. Detect pesticides in control (nonspray) blocks.

2. Detect presence and amount of pesticides in sensitive areas containing water, birds, insects, fish, wild and domestic mammals, bees, farmsteads, and recreation areas, and concentrations of people.

3. Provide data base for predicting drift.

4. Compare drift from different spray systems or tank mixes.

5. Define meteorological conditions that will minimize drift.

6. Provide information for future environmental analysis.

7. Provide data to defend against allegations of damage.

8. Validate drift models.

9. Develop environmental policies.

10. Provide data for improvement of future spray operations.

PURPOSE AND SCOPE OF DRIFT SAMPLING

After the amount and extent of drift have been measured, it is useful to predict the relationship between deposits on artificial collectors and deposits on natural collectors. This can be done in two ways:

1. By applying equations for atmospheric transport and diffusion and physics of particle behavior. A well developed body of knowledge is available for specific targets and conditions.

2. By comparing statistical correlations between deposits measured on artificial collectors and those on natural collectors with other parameters such as the stability ratio. Results of comparing these relationships in agricultural and forest spraying have been reported by Armstrong (1975) and Yates and Akesson (1975).

Choosing the most effective sampler depends on a clear understanding of the principles of drift sampling. When a pollutant is introduced into the atmosphere, its transport is influenced by how it is released and the nature of the atmosphere, particularly the air movement. Except for a few special cases, the farther downwind the cloud travels, the more dispersed the pollutant becomes.

Equations predicting diffusion were made as early as 1855 based on molecular agitation. Later equations incorporated the effect of turbulent eddies. Equations developed by Cramer and others (1972) as well as other investigators incorporated the effect of gravity on particles of significant size. All these equations are extremely complex, but are available in meteorological source materials.

Common Forms for Reporting Drift

Determining drift depends not only on complex mathematical computations but on the source of pollutant as well. Common classifications of sources for measuring pollutants are:

SOURCE	EXAMPLE
Continuous Point	Plume from smoke stack
Continuous Line	Busy Highway
Continuous Area	City
Instantaneous Point	Explosion
Instantaneous Line	Single swath of spray aircraft

If the amount and size distribution of a pollutant, as well as airspeed and air density, are measured and recorded continuously, the data may be presented in several ways. If all parameters are known, data can be converted from one form to another, in addition to the simple conversion from English to metric units. However, because it is seldom practical or economical to measure and record all the parameters, in practice the terms cannot be readily converted from one expression to another. It is important to establish how to present the data, since a different kind of sampler may be needed to measure each form. For example, a sampler suitable for measuring dosage may not be suitable for measuring flux (table 1).

The volume, number of particles, or mass of particles are sometimes reported by several categories of droplet size rather than the total number of particles, volume, or mass.

Each of these terms is appropriate for some applications and each describes a significant physical property. A clear understanding of each term is essential to understanding the significance of the reporting standard.

Definition of Terms

Concentration - Concentration is the amount of aerosol contained in a unit volume of air (fig. 2). It is usually

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Table 1.--*Standard terms for reporting presence of aerosols or particulates*

TERM	SYMBOL	UNITS	COMMENTS
Concentration	$\frac{\mu g}{m^3}$	$\frac{\text{microgram}}{\text{meter}^3}$	
Dosage	$\frac{\mu g.sec}{m^3}$	$\frac{\text{microgram second}}{\text{meter}^3}$	
Flux	$\frac{\mu g}{m^2.sec}$	$\frac{\text{microgram}}{\text{meter}^2\ \text{second}}$	usually vertical
Total flux	$\frac{\mu g}{m^2}$	$\frac{\text{microgram}}{\text{meter}^2}$	usually vertical
Parts per million	ppm		nondimensional volume ratio
Deposit	$\frac{\mu g}{m^2}$	$\frac{\text{microgram}}{\text{meter}^2}$	usually horizontal
Droplet deposit density	$\frac{\text{drops}}{cm^2}$	$\frac{\text{drops}}{\text{centimeter}^2}$	

given as micrograms (μg) per cubic meter (m^3). The volume of air may be stationary or moving, but unless the windspeed is known, the concentration cannot be used to compute the total aerosol moving past a given point. Concentration is useful for setting standards for inhaled aerosols. Inhalation takes place at a fixed rate, independent of windspeed or total aerosol passing a given point.

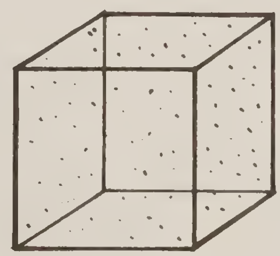

Figure 2.--Concentration - Mass or volume of aerosol in a given volume of air.

If an aerosol is injected at a fixed rate into moving air, the concentration will vary inversely with the windspeed. This is illustrated in figure 3 with a smoke plume at two windspeeds. On the other hand, if an aerosol is already present and the air velocity is suddenly increased by flowing through a reduced cross section of a duct or being channeled through a narrow canyon, the concentration should remain nearly constant.

It is difficult to measure concentration from an instantaneous source since the

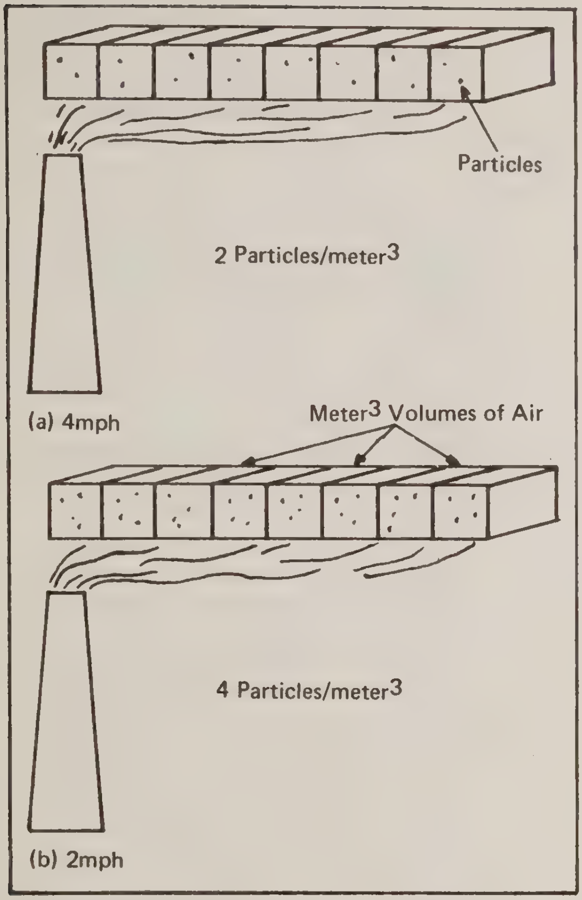

Figure 3.--Effect of wind speed on concentration from a point source without cloud expansion.

concentration varies near the source from zero to peak and back to zero in a short time. At long downwind distances, when a cloud is more diffuse in the alongwind direction, the time required for cloud passage increases and variations in concentration are not as rapid. Normally the exact time the aerosol is present is not known. A technique known as grab sampling has been used to overcome this problem. Grab sampling consists of quickly capturing a volume of air by some means such as a balloon or pump and analyzing it, usually in a laboratory. Several samples would have to be taken at intervals to establish the variation of concentration.

Dosage - The physical significance of dosage is summation of concentration with respect to time. If the concentration is constant, dosage is simply the product of concentration and time. Otherwise, dosage is the area under the curve when concentration is plotted against time. Figure 4 illustrates this concept for two types of sources. The units for dosage are $\mu g.sec/m^3$.

In practice dosage is usually determined by dividing the total weight of the aerosol sample by the sampling rate.

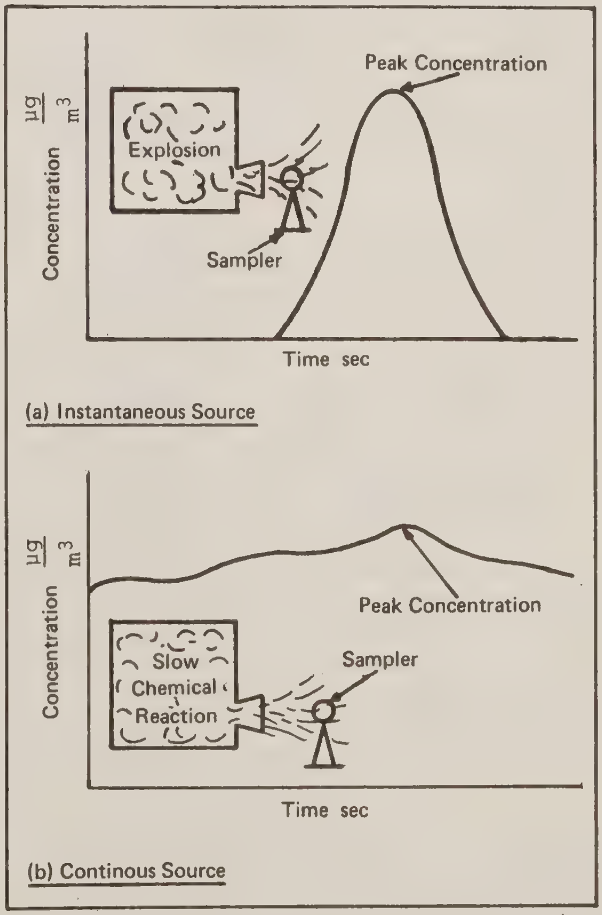

Figure 4.--Variation of concentration from two types of sources.

Dosage is frequently used in public health standards to set limits when low concentrations over a long period of time are harmful.

Flux - Flux in many physical sciences denotes rate of passage of energy or substance per unit area. For an aerosol it would be weight of aerosol per unit area per second $\mu g/m^2$.sec. Figure 5 depicts a large fixed reference volume through which a spray cloud is passing. Imagine a 1 square meter window at the bottom of the cube at ground level and another window of the same size on the leeward side of the cube. If the spray cube contains a range of droplet sizes, some will settle or deposit through the horizontal window. The droplets that pass through the vertical window are representative of the airborne portion of the cloud. The flux would represent the weight of aerosol passing through the 1 square meter window in 1 second.

Total Flux - By summing all flux over a period of time, total flux in $\mu g/m^2$ can be measured. In the case of an instantaneous source, total flux represents the total material passing through the imaginary vertical window. It can be given in the same units used for deposition on horizontal cards.

Parts per million (ppm) - The amount of a pollutant is sometimes expressed as ppm, the number of pollutant molecules per million molecules of air. This is concentration by volume and can be converted to mass concentration by suitable formula. Since ppm is a measure of concentration, it does not indicate total material passing a given point unless airspeed and density are known.

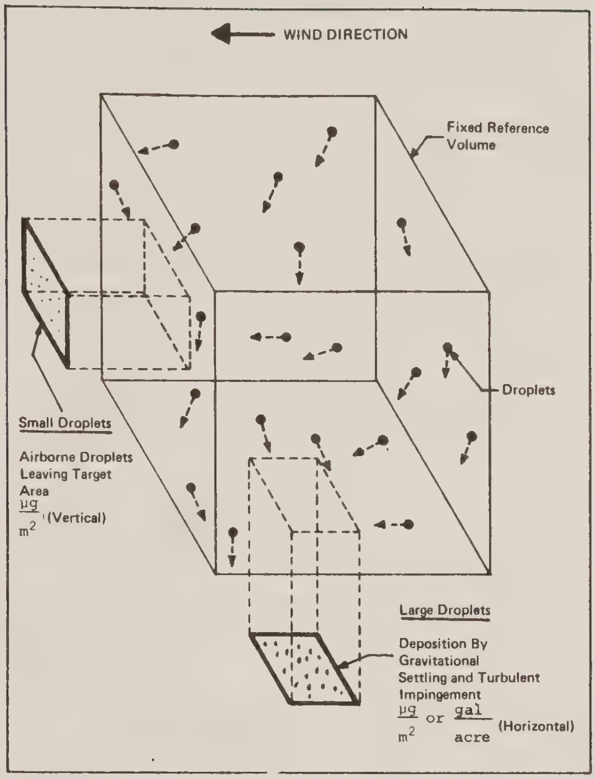

Figure 5.--Comparison of vertical flux and horizontal deposit.

Deposit - Deposit is usually associated with gravity samplers. Samplers collect droplets that have significant gravitation settling velocity and, in the presence of turbulent air, smaller droplets that are impinged on the sampler. The units may be $\mu g/m^2$ but are usually given in gallon or ounces per acre. These units can be directly compared to the units of total flux.

All of the above terms, with the exception of ppm, are expressions of weight. The same concepts can be used to express volume of aerosol or numbers of particles or droplets.

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Pesticide and herbicide drift studies have been reported using all these terms: dosage, concentration, and deposit (Murray and Vaughan 1969); concentration (Ware and others 1972); dosage and deposit (Barry and others 1974); and total flux and deposit (Yates and Akesson 1975).

DRIFT SAMPLERS

There are many commercial and homemade sampling devices, ranging from extremely simple inexpensive devices to highly sophisticated expensive devices. Each has shortcomings and our preliminary investigation has not shown any one sampler to be obviously most suited for our objective of sampling aerosol carried off target by surface winds before it is deposited on soil, plants, water, or animals (heavy outline fig. 1). Further evaluation or modification of samplers must compare their performance.

Following is a list of criteria for evaluating samplers in order of decreasing importance. The first six items are most important.

Evaluation Criteria

Sampler should be:

1. Useful for intended application
2. Evaluation must consider cost factors:
    - Initial cost
    - Cost to deploy and operate
    - Cost to analyze
3. Rugged and operable in field environment
4. Readily portable
5. Capable of being balloon supported up to 150 feet
6. Simple to operate
7. Suitable for remote control
8. Battery powered or not require power
9. Independent of tracer in spray
10. Have proven performance
11. Available for 1978 field season
12. Suitable for quick and dirty approximation in field
13. Suitable for analysis without extensive lab facilities

Samplers to be Evaluated

The common methods used for aerosol sampling operate on a few basic principles. MEDC will review the specific sampling devices and evaluate their performance.

Basic types of samplers available are:

Gravitational settling

Impaction

Suction

Grab sampling

Exotic

Samplers to be considered in MEDC evaluation are:

Gravitational Settling - Horizontal surfaces have been used extensively for collecting airborne pollutants. Large droplets settle at their terminal velocity and are retained on the surface. For smaller droplets, deposition is a function of windspeed, turbulence, droplet size, concentration, and possibly other undefined factors. This makes it difficult to obtain reproducible results for smaller droplets whose terminal velocity approaches the

turbulent eddy velocity. For larger droplets these samplers are fairly reliable.

Impaction - The most common impaction sampler is a horizontal or vertical cylinder. Droplets approaching the cylinder are impacted upon the surface. However, based on droplet size and cylinder size, some droplets will be deflected around the sampler. If the windspeed is known, calculations can correct for collection efficiency. By using a variety of sizes and position of cylinders a collection efficiency can also be made without knowing windspeed. One of the principal disadvantages of the device is its low sampling rate at low windspeeds.

Another version of the impaction sampler, which is useful even in still air, is the rotating impactor. It may be a small bar, microscope slide, or cylinder that is rotated about an axis parallel to but not coincidental with its own axis. High rotational speed essentially masks the normal windspeed and can give a high collection efficiency for even small droplets. If it is a constant speed device, it will also have a fixed sampling rate. A rather subtle but important shortcoming is that it cannot be used to measure total flux unless the windspeed is known. Results are usually presented as dosage. It is expected that a region of turbulence will surround the sampling surface, making it difficult to apply collection efficiency equations based on laminar flow. Therefore they are usually calibrated for each particle or droplet size. With larger droplets and heavy loading, centrifugal detachment and reentrainment may be experienced.

Suction - A more sophisticated group of samplers is based on the principle of drawing air into an entrance with a pump and causing the droplets or particles to impinge, impact, or settle on some internal sampling surface. All of these devices require external power. High volume samplers commonly used for air pollution studies require a gasoline engine, high amperage batteries or alternating current to power the vacuum pump. Commercial units small enough to be worn on the lapel and battery powered are also available. However, they will have lower sampling rates and require a more sensitive analytic assessment technique.

To obtain an isokinetic sample the entrance must face directly into the wind and have the same entrance velocity as the mean windspeed. This can seldom be achieved in practice, so a bias due to anisokinetic sampling must be expected. Total flux cannot be measured unless windspeed is known.

Grab Sampling - It is principally useful for measuring concentration which may be expected to vary with time. Grab sampling is accomplished by quickly capturing a volume of air in some sort of pump and returning it to a laboratory for analysis.

Exotic - Other systems of tracking and measuring aerosols are in use. Some of these are light scatter, lidar tracking, and radar tracking. Most appear to be principally laboratory or research devices and are too bulky or expensive for routine forest use.

DISCUSSION

It is important to establish standard methods and uniform units for reporting drift if sampler performance is to be compared and results of drift sampling are to be biologically useful.

Aerial spraying is usually done during a short period of time with interruptions from loading or equipment failure. Therefore, it seems reasonable to consider the source an instantaneous line source, which means that there will be wide fluctuations in downwind concentration depending on downwind distance and the alongwind extent of the cloud. To measure actual levels of concentration would require grab sampling or some similar technique. Although dosage is useful if you want to know assimilation at a fixed rate of respiration, total flux, which indicates the amount of material available for deposit on travel downwind, appears to be the most useful form for our objective.

Selection of droplet size range will also influence selection of a sampler. Dennis (1976) defines coarse aerosol from 10 to 40 µm. This classification is also defined as fog. Mist is defined as droplets produced by atomization or condensation processes and larger than 40 µm. Since we may be concerned with drift over short distances, the upper limit of the range might be extended to at least 50 µm. Most samplers are not suitable for collecting a wide range of droplet size with reasonable efficiency. With this in mind, a lower limit for droplet size of 15 µm and an upper limit of 50 µm may be a reasonable selection.

The minimum detection level in terms of total flux or concentration is also important in selecting a sampler. One 20 µm drop per square centimeter is equivalent to 4.2×10^{-9} gram per square centimeter or 0.418 gram per hectare or an average concentration of 1.3×10^{-11} gram per liter for 1 hour of sampling in a 2 mph wind. Yates and Akesson (1975) report measuring between 0.14 and 10 grams per hectare 1000 meters downwind from an agricultural spray using high volume air sampling equipment. Unless a need for more sensitive detection can be shown, a lower limit of 10^{-8} gram per square centimeter total vertical flux should be realistic for our objective.

SUMMARY

In an attempt to find a standard sampler for measuring coarse aerosol carried off target by surface winds, MEDC recommends the following:

1. Assume a nearly instantaneous line source.

2. Use total flux as primary reporting standard for drift.

3. Establish minimum detection level not less than 10^{-8} gram per square centimeter.

4. Sample for droplets from 15 to 50 µm.

We are soliciting comments on our recommendations from individuals responsible for conducting spray projects or assessing impact of drift. We are particularly concerned with: (a) purpose and priority of drift sampling; (b) criteria for evaluating samplers; (c) standards for reporting; (d) sampling size range and detection levels.

Comments will be summarized by MEDC. A group of representatives from both the National Forest system and Research, who are experienced in aerial application and environmental impacts, will be selected to review and recommend for approval the reporting standard and criteria for drift monitoring. MEDC will use these reporting standards and drift sampling criteria to develop a standard sampler for detecting and measuring coarse aerosol.

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